SAMI PETTERSSON – Resonant-type filters are used as supply filters in grid-connected, pulse-width modulated (PWM) power converters to ensure compliance with power quality requirements set by international and country-specific standards. New semiconductor devices with lower power losses, as well as multilevel converter topologies, enable power converter designs with higher switching frequencies. Because the requirements for passive filtering are then reduced, higher power densities can be achieved. However, supply filters with high resonance frequencies in these devices may cause problems for existing control systems. This article – the fourth and final one in the “Taming the power” series – describes advanced control methods developed by ABB that solve these resonance problems.

Putting a damper on resonance

Advanced control methods guarantee stable operation of grid-connected low-voltage converters
Grid-connected, low-voltage (LV) power conversion systems with a PWM active front-end are nowadays used in various applications, many of which are found in ABB’s product portfolio: four-quadrant motor drives, wind power converters, photovoltaic (PV) inverters, uninterruptible power supply (UPS) systems and active power quality conditioners, for example.

An active front-end in a grid-connected power conversion system makes it possible to fully utilize the energy transfer capacity of the system and maximize the power quality. Furthermore, it enables bidirectional energy flow, ie, to and from the grid.

The main circuit of a typical grid-connected LV converter is depicted in Fig. 1.

When using a PWM converter to interface to a power distribution grid, a supply filter between the converter and the grid is usually required so that the grid currents can be controlled and the power quality requirements set by international and country-specific standards can be met. The most commonly used supply filter structure is the so-called LCL filter, which consists of two sets of inductors with filter capacitors placed between them.

The LCL filter is a resonant-type filter whose resonance frequency is typically tuned to be between 20 and 40 percent of the PWM frequency. This guarantees sufficient attenuation of the undesired high-frequency current components generated by the PWM converter. The drawback of resonant filters is that, without a proper damping, they may cause unwanted resonance in the system and make the grid current control unstable.

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Resonance damping
There are two basic approaches used to combat unwanted resonances: passive damping and active damping. In the former, resistors are added to the filter structure to passively damp the resonance. However, these resistors consume additional power and the overall filtering performance is inferior to that of the active damping approach.

Active damping methods are implemented in the control system without the need to physically modify the supply filter. The idea is either to limit the bandwidth of the current controller so that the PWM converter does not excite the resonance of the LCL filter or to actively damp the resonance with feedback, eg, from the LCL filter capacitor voltage or current.

Method A: control bandwidth limitation
The simplest method of dealing with the LCL filter resonance is to limit the bandwidth of the current controller so that it is below that of the resonance frequency. This can be done by add-
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LCL filter capacitor voltage or current. These parameters can be either measured or estimated. Because additional measurements increase the system cost, estimation methods are usually preferred in commercial products.

Method B: active resonance damping

Active resonance damping methods typically utilize information about the LCL filter capacitor voltage or current. These parameters can be either measured or estimated. Because additional measurements increase the system cost, estimation methods are usually preferred in commercial products.

➔ 4 presents a block diagram of a grid current control system with active resonance damping based on the LCL filter capacitor voltage feedback. To avoid the need for additional measurements, an observer is used to estimate the LCL filter capacitor voltage on the basis of the converter voltage reference, and the measured grid voltage and converter current [1,2].

The operating principle of active damping is that if any resonance starts to appear in the LCL filter capacitor voltage, the active damping mechanism will modify the converter voltage reference so that the resonance disappears.

Because active damping should only react to voltage harmonics, a notch filter is used to remove the funda-

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The control system has been implemented with a 300 MHz 32-bit floating-point digital signal processor. The PWM carrier frequency is 10 kHz and the sampling and control execution frequency 20 kHz. The resonance frequency of the LCL filter is approximately 3.2 kHz.

Active damping methods are implemented in the control system without the need to physically modify the supply filter. The major benefit of active damping is its adaptive nature, which also makes it effective against disturbances originating from the grid. As in the case of all active methods, the bandwidth of active damping is limited by the sampling and PWM carrier frequencies. Therefore, to ensure good performance, the PWM carrier frequency should be at least three to four times higher than the LCL filter resonance frequency.

Experimental verification
The performances of the two control methods introduced above have been experimentally verified in a 40 kVA grid-connected, three-phase PWM rectifier with a resistive load. The converter is connected to a standard three-phase 400 V LV grid. The control system has been implemented with a 300 MHz 32-bit floating-point digital signal processor. The PWM carrier frequency is 10 kHz and the sampling and control execution frequency 20 kHz. The resonance frequency of the LCL filter is approximately 3.2 kHz.

➔ 6 demonstrates what happens if the LCL filter resonance is not taken into account in the control system. The grid current control is unstable and the converter stops because of an overcurrent trip caused by the resonating grid currents.

➔ 7 shows that when a properly designed LPF is placed in series with the proportional gain of the current controller, no resonance occurs in the grid currents and the converter can...
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come too sensitive to high-frequency disturbances. The two methods presented above are specifically developed for this type of situation. Their implementation requires only marginal computational effort from modern-day processors and no additional voltage or current sensing equipment is needed.

Even though the methods have been presented as separate, they are in reality complementary. When used together, the LPF makes the current control less sensitive to high-frequency disturbances, whereas the active damping deals with all disturbances that can be detected in the LCL filter capacitor voltage. This renders the precise design of the LPF unnecessary.

Experimental tests have proven that both methods can provide a stable grid current control with a compact LCL filter without compromising the dynamic response of the control system.

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References